

“From Dust to Planetesimals”

Ringberg Castle, September 2006

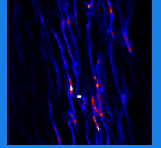
The gravitational collapse of preplanetesimal islands in a turbulent flow

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Hubert Klahr, Thomas Henning



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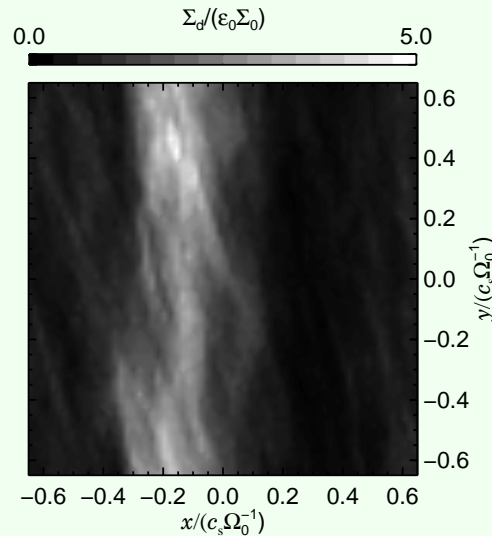
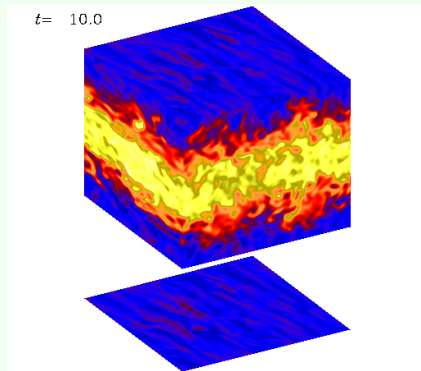
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1. Turbulence

Full 3-D models of turbulence and dust in protoplanetary discs show enormous transient **dust density concentrations**:



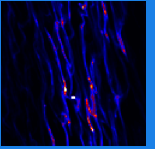
(Johansen & Klahr 2005; Johansen, Klahr, & Henning 2006).

Barge & Sommeria (1995):

Dust particles get trapped in vortices.

Klahr & Lin (2001), Haghighipour & Boss (2003):

Dust particles are trapped in any high-pressure region.



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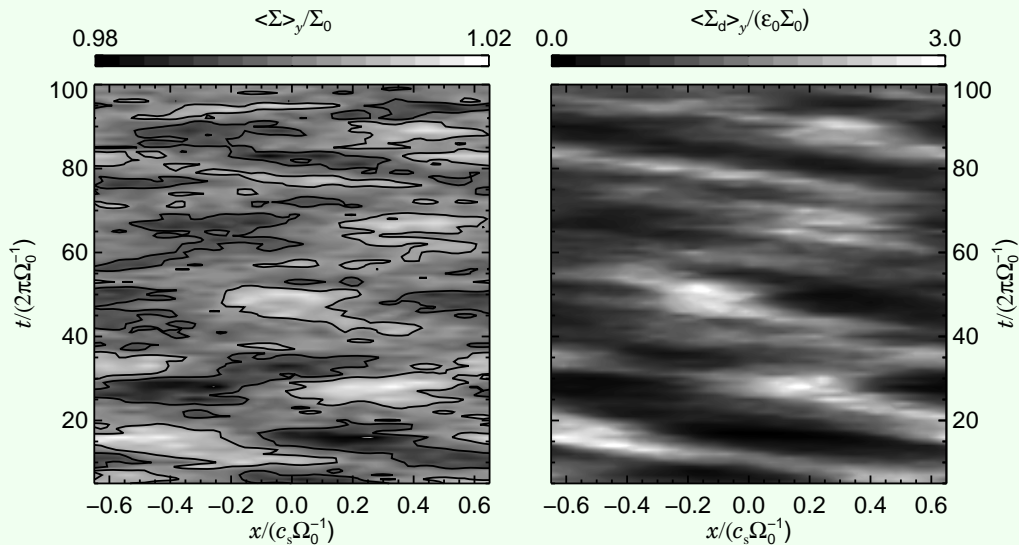
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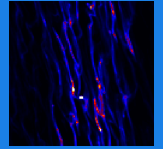
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Dust overdensities

Gas and dust column density as a function of radial distance from centre of box x and time t in local orbits:



Strong correlation between gas and dust overdensities.



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2. Self-gravity

New term in equation of motion of dust

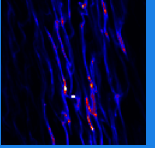
$$\frac{d\mathbf{v}}{dt} = \dots - \nabla\Phi.$$

The gravitational potential of the dust grains Φ is found by solving the [Poisson equation](#)

$$\nabla^2\Phi = 4\pi G\rho_{\text{dust}}$$

We have developed a fully parallel shearing sheet Poisson equation solver. Technical details:

- Dust grains are treated as particles
- Triangular Shaped Cloud assignment/interpolation scheme (Hockney & Eastwood 1981)
- Potential is solved on the mesh using FFT method
- Keplerian shear included (following Gammie 2001)



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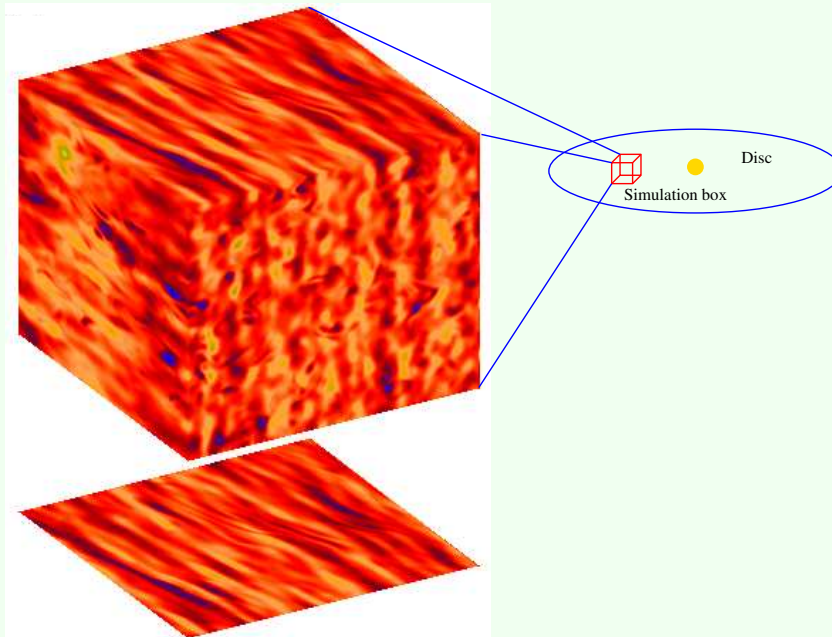
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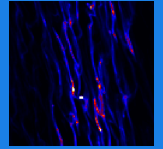
3. MRI turbulence

Magnetorotational turbulence robust source of turbulence in protoplanetary discs if ionisation fraction sufficiently high. Prototype of Kolmogorov turbulence.



Shearing box, no vertical gravity on the gas.

Code: The Pencil Code [MHD code, finite differences, 6th order in space, 3rd order in time, Brandenburg (2003)]



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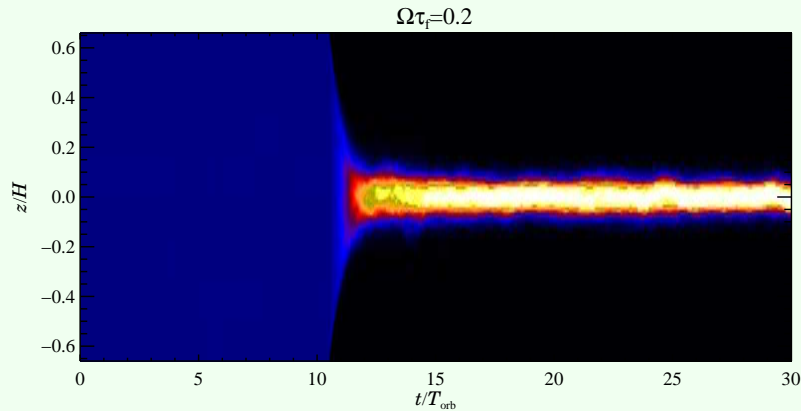
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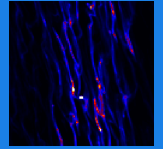
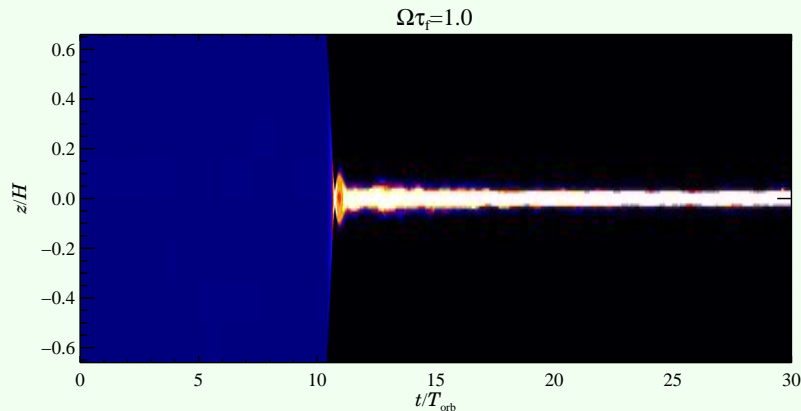
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4. Dust

Sedimentation of **20 cm dust rocks** to the mid-plane:



Sedimentation of **1 m dust boulders**:



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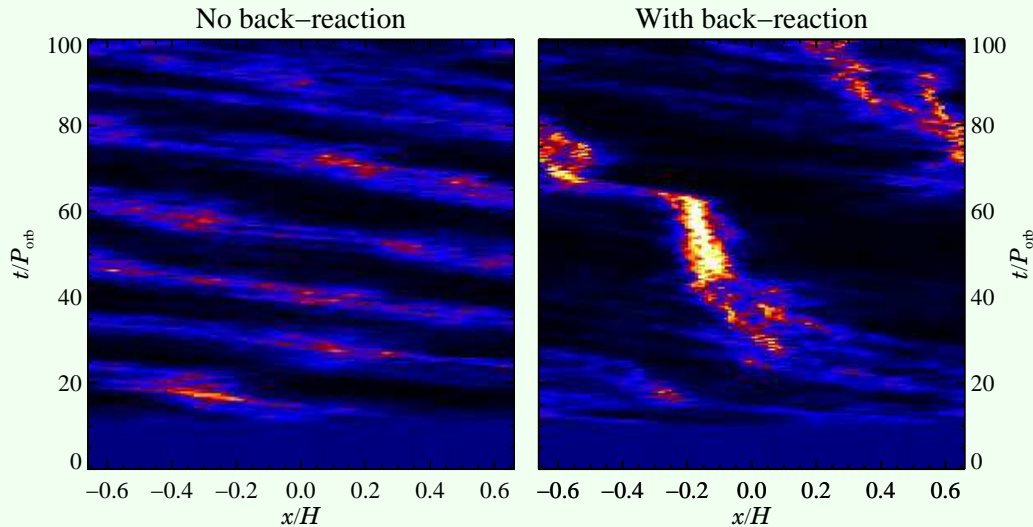
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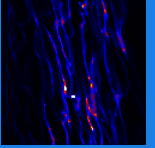
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Overdense seeds

Dust column density as a function of radial coordinate x and time t measured in orbits:



Turbulent overdensities (Johansen, Klahr, & Henning 2006) combined with **streaming instability** (Youdin & Goodman 2005, Johansen & Youdin in preparation) create transient, overdense “seeds” where self-gravity is important.



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Cooling

Drag force cooling

The dissipation of kinetic energy caused by drag force between **dust with velocity \mathbf{w}** and **gas with velocity \mathbf{u}** is

$$\frac{\partial e_{\text{kin}}}{\partial t} = -\frac{\rho_{\text{d}}}{\tau_{\text{f}}} |\mathbf{w} - \mathbf{u}|^2. \quad (1)$$

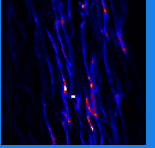
Collisional cooling

Collisional time-scale is $\tau_{\text{coll}} = \ell / \langle v \rangle$. Assume spheres and insert friction time τ_{f} ,

$$\tau_{\text{coll}} = \frac{\tau_{\text{f}}}{3 \frac{\langle v \rangle}{c_{\text{s}}} \frac{\rho_{\text{dust}}}{\rho_{\text{gas}}}}.$$

Becomes comparable to friction force when

$$\rho_{\text{dust}} / \rho_{\text{gas}} = 1 / (3 \langle v \rangle / c_{\text{s}}) \sim 10 \dots 100$$



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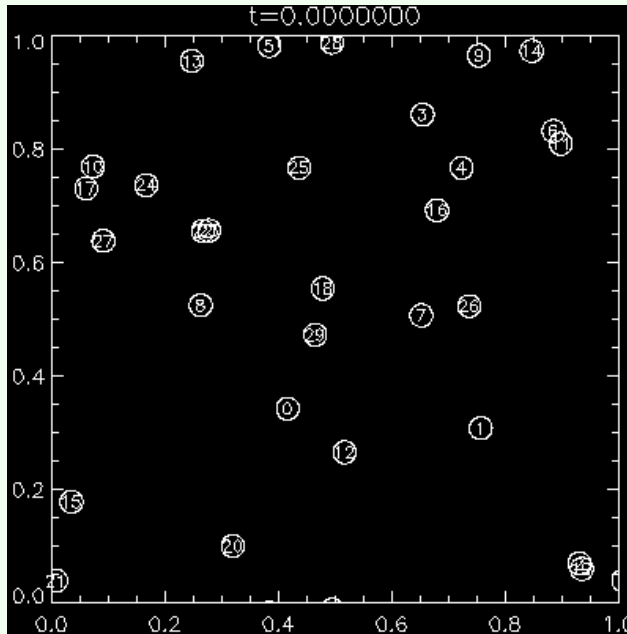
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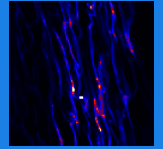
Coefficient of restitution

Collisions can cool preplanetesimals if the collisions are inelastic.

Toy collision model:



Collisional cooling is good for self-gravity because dust rms speed counteracts collapse. We parameterize collisional cooling with a coefficient of restitution = 0.1 (Hartmann 1985) in the MHD simulations.



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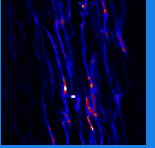
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WARNING!

The following results are based on considering only a single dust size. We realize that results may change if a more realistic dust size distribution is used.

We are working together with Frithjof Brauer and Kees Dullemond on putting several simultaneous dust sizes in the simulations.

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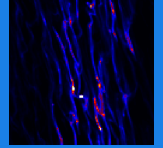
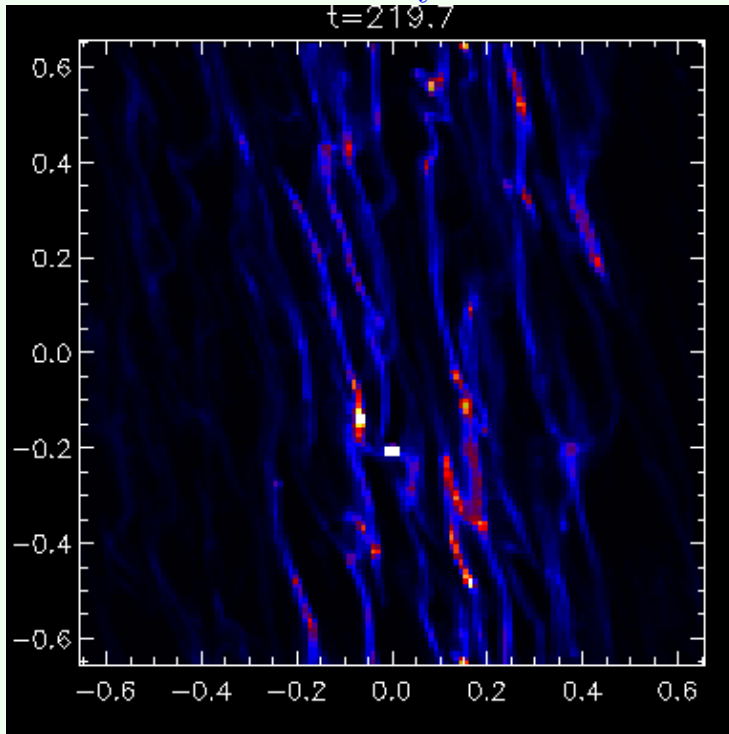
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Self-gravity

Magnetorotational turbulence, 128^3 grid resolution with 2,000,000 embedded dust particles. Gas column density is $\Sigma = 300 \text{ g cm}^{-2}$ at $r = 5 \text{ AU}$, around two times MMSN.

Column density of dust:



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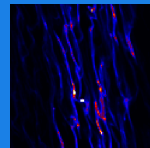
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5. Conclusions

We have simulated planetesimal formation in a turbulent protoplanetary disc. Conclusions:

- It is possible to form planetesimals by self-gravity in a turbulent disc.
- A disc mass that is comparable to the minimum mass solar nebula is sufficient.
- Dust grains trapped in “vortices” and high-pressure regions combined with the collective streaming instability produce overdense seeds where self-gravity is important.
- Drag force cooling and collisional cooling are efficient ways to cool down the dust rms speed.

256^3 simulations are running now...



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